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MEMORANDUM REPORT
CAA-MR-99-14

STOCHASTIC ANALYSIS OF RESOURCES FOR DEPLOYMENTS AND EXCURSIONS (SARDE)

JULY 1999

PREPARED BY
FORCE STRATEGY DIVISION

CENTER FOR ARMY ANALYSIS
6001 GOETHALS ROAD
FORT BELVOIR, VA 22060-5230

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13. ABSTRACT (Maximum 200 words)

This quick reaction analysis is a follow-on to the Stochastic Analysis for Deployments and Excursions (SADE) Study performed in 1998. The effort employed a simulated queuing environment, the parameters of which are statistically derived from historical data, to estimate the frequency, duration, and simultaneity of future smaller-scale contingencies (SSCs) in which the Army might need to respond. Using this construct, the mission task organized forces (MTOFs) needed to respond to each SSC were identified and the required units counted. Through replication, a probability distribution of the simultaneously required units was developed. This analysis informed decision makers in the resourcing phase of the Total Army Analysis 2007 Study.

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Deployment analysis, smaller-scale contingency, forecast, standard requirement code (SRC)

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STOCHASTIC ANALYSIS OF RESOURCES FOR DEPLOYMENTS AND EXCURISIONS (SARDE)

SUMMARY

1. SPONSOR. Chief, War Plans Division, Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS), Headquarters, Department of the Army (HQDA), ATTN: DAMO-SSW.

2. PURPOSE. The sponsor requested analytical support for the upcoming Total Army Analysis – 2007 in the area of determining force structure requirements for smaller-scale contingency (SSC) operations.

3. OBJECTIVES. The quick reaction analysis (QRA) was conducted in order to combine the results of the previously completed Stochastic Analysis for Deployments and Excursions (SADE) Study and development of mission task organized forces (MTOFs) in the Objective Force Planning New and Extended (ONE) Study. Thus, expected requirements for each type unit were computed based on anticipated occurrence and duration of future SSCs.

4. ASSUMPTIONS. The major assumptions underpinning this methodology are that future responses to worldwide crises will follow the pattern of the recent past (1990-1997) and that the MTOFs developed represent a range of situations that might be encountered in future SSCs.

5. LIMITATIONS

a. The data base of historical developments continues to be updated as new information is discovered. Therefore, some deployments that have occurred in the past may not be included.

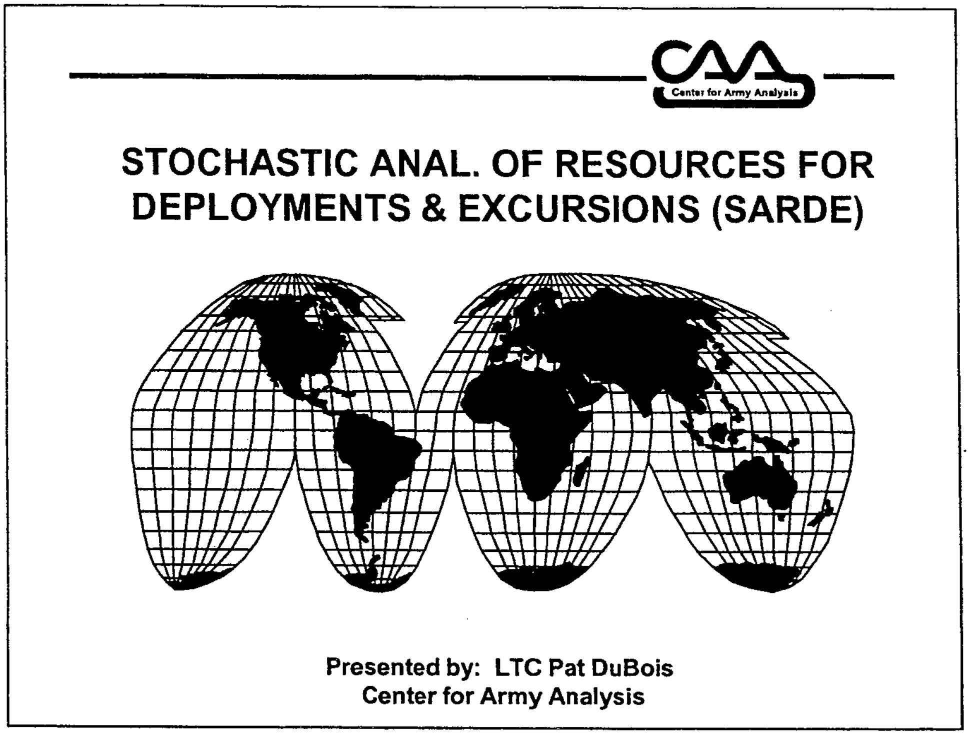
b. Developed MTOFs are the product of expert judgement, and it is recognized that multiple solutions exist to the problem of designing a force to respond to the various SSCs. The MTOFs used are the result of a coordinated effort of the Army Staff (ARSTAF) and the staffs of the affected areas of responsibility.

6. APPROACH. The methodology employed makes use of the SADE model that represents the occurrence and response to SSCs as a queuing system whose parameters are estimated based on historical data. The system is simulated repeatedly to produce a range of anticipated outcomes. For each occurrence of an SSC, the appropriate MTOF is applied. The usage of the individual type units is recorded. This information is used to compute a probability distribution on the number of each type unit used simultaneously.

7. QRA PRODUCT. See attached annotated briefing.

8. QRA DIRECTOR. This QRA was directed by LTC Patrick J. DuBois, Force Strategy Division, Center for Army Analysis.

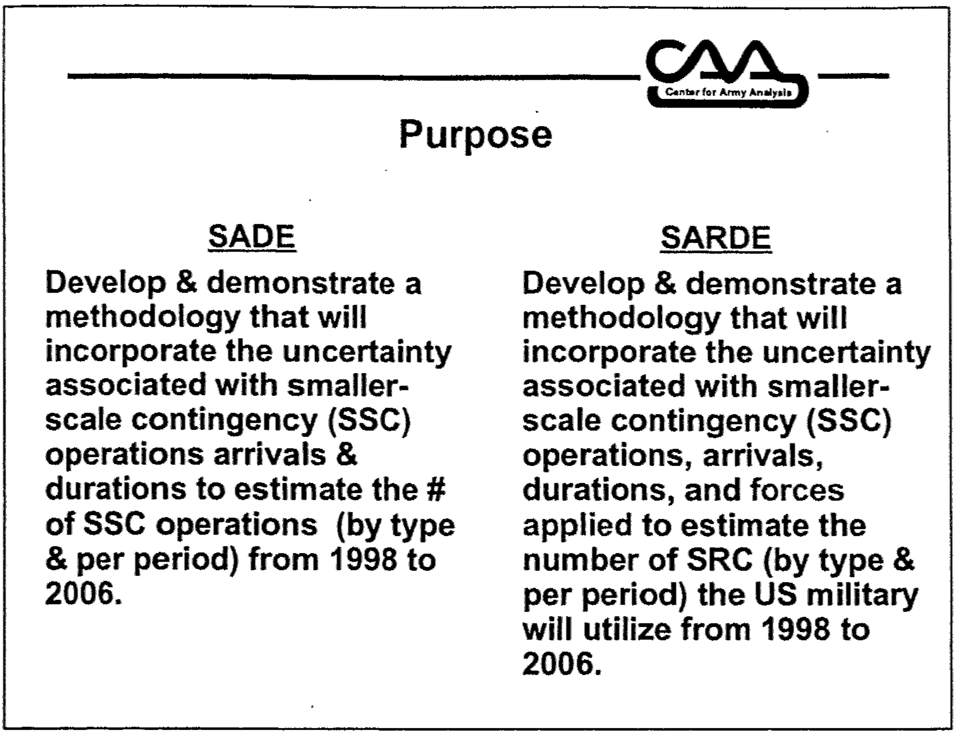
9. COMMENTS AND QUESTIONS. Queries concerning this methodology may be sent to the Director, Center for Army Analysis, ATTN: CSCA-FS, 6001 Goethals Road, Fort Belvoir, VA 22060-5230.



STOCHASTIC ANAL. OF RESOURCES FOR DEPLOYMENTS & EXCURSIONS (SARDE)

Presented by: LTC Pat DuBois
Center for Army Analysis

The Stochastic Analysis of Resources for Deployments and Excursions (SARDE) Quick Reaction Analysis (QRA) was requested and sponsored by the War Plans Division (SSW) of the Office of Deputy Chief of Staff for Operations and Plans (ODCSOPS), DAMO-SSW.

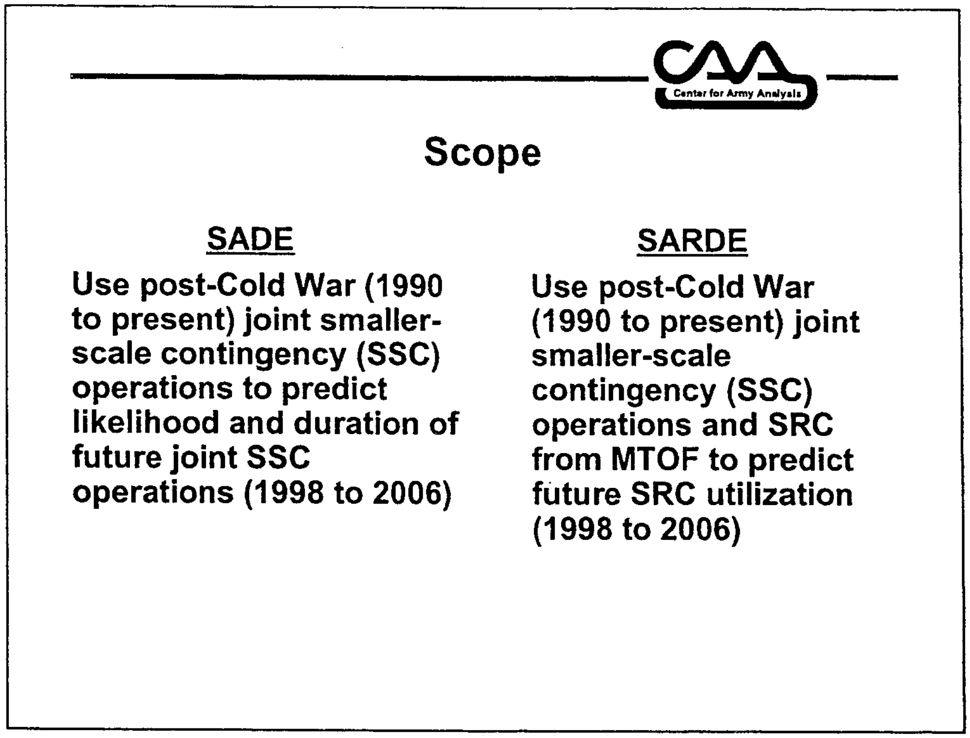


Center for Army Analysis

Purpose

SADE	SARDE
Develop & demonstrate a methodology that will incorporate the uncertainty associated with smaller-scale contingency (SSC) operations arrivals & durations to estimate the # of SSC operations (by type & per period) from 1998 to 2006.	Develop & demonstrate a methodology that will incorporate the uncertainty associated with smaller-scale contingency (SSC) operations, arrivals, durations, and forces applied to estimate the number of SRC (by type & per period) the US military will utilize from 1998 to 2006.

SARDE is a follow-on analysis to the Stochastic Analysis for Deployments and Excursions (SADE) Study. SADE's purpose was to develop and demonstrate a methodology that incorporates the uncertainty associated with smaller-scale contingency (SSC) operations' arrival and duration to estimate the number of SSC operations, by type and per period, from 1998 to 2006. After obtaining a forecast of an SSC, a natural next step would be to estimate the number of forces, by type, that would be required to service the forecasted SSC. Hence, SARDE was requested, and its purpose was to develop and demonstrate a methodology that incorporates the uncertainty associated with SSC operations' arrivals, durations, and forces applied to estimate the number of standard requirement codes (SRCs), by type and per period, the US military will utilize from 1998 to 2006.



Scope

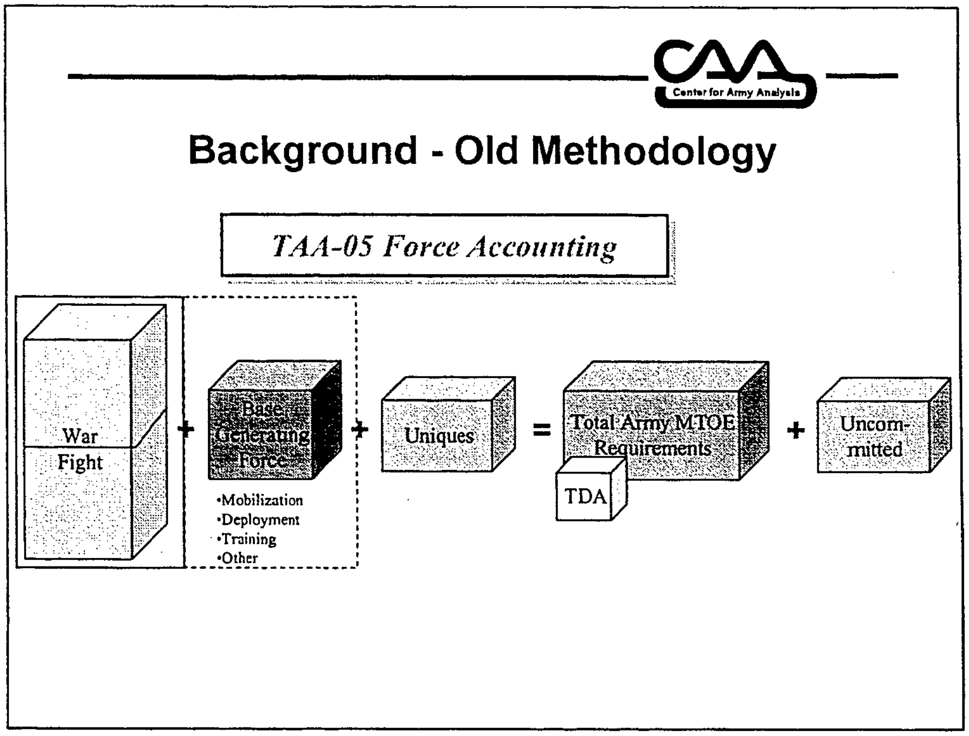
SADE	SARDE
Use post-Cold War (1990 to present) joint smaller-scale contingency (SSC) operations to predict likelihood and duration of future joint SSC operations (1998 to 2006)	Use post-Cold War (1990 to present) joint smaller-scale contingency (SSC) operations and SRC from MTOF to predict future SRC utilization (1998 to 2006)

Given the relationship between SADE and SARDE, it is not surprising that their scopes are similar. SADE uses post-Cold War (1990 to present) joint SSC operations to predict the likelihood and duration of future joint SSC operations (1998 to 2006). Likewise, SARDE uses post-Cold War (1990 to present) joint SSC operations which include the forces applied and SRCs from the mission task organized force (MTOF) process to predict future SRC utilization (1998 to 2006). The use of historical order of battle versus existing MTOFs will be addressed later in this report.

Assumption/Limitations

- Assume the future is going to be similar to the past
- The small number of data points in some SSC categories is not statistically significant, causing inferences from the data to be suspect

Forecasting is always a problematic task. The forecasts produced by the SADE and SARDE methodologies are purely baseline. That is, the analyst assumes the future is going to be similar to the past. Therefore, the reader, based on his/her opinion, can increase/decrease the forecast dependent upon whether he/she thinks there will be more or less of a particular SSC in the future based upon external factors. Those external factors could be environmental conditions, foreign government political situations, or US government political situations, to name but a few. Hence, the assumption is not necessarily a limitation--it merely addresses future uncertainty and treats it as a fact so that a baseline can be developed.



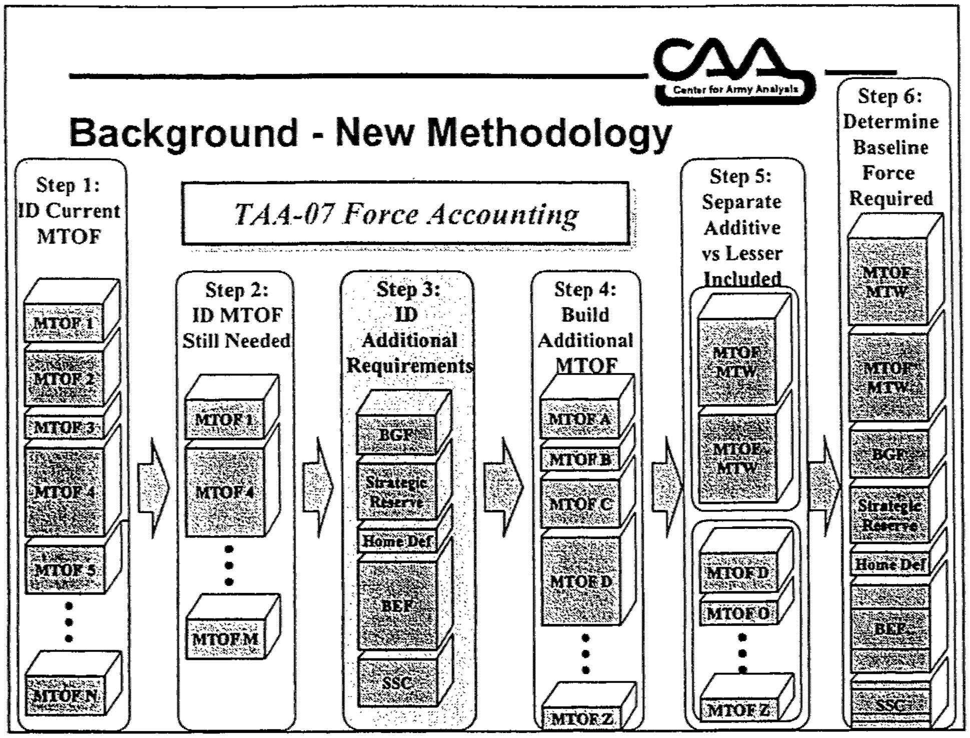
Background - Old Methodology

TAA-05 Force Accounting

The fall of the Berlin Wall on November 9, 1989 symbolized the end of the Cold War between the two world superpowers, the United States (US) and the Soviet Union. The event also marked the transition from a bipolar world, with most countries allied to one of the superpowers, to a multipolar world in which countries tend to act independently according to their own perceived interests.

This transition caused the US military to no longer focus its attention exclusively upon conflict with the Warsaw Pact nations in Central Europe; instead, it prepares to respond both to major theater wars (MTWs) as well as to SSCs, with the geographical locale in each case being uncertain. These new strategic and operational demands compel the US Army to carefully and frequently reassess its force structure, major weapon systems, and tactics. The process used is the US Army's 7-year Planning, Programming, Budgeting, and Execution System (PPBES). The focus of the planning effort is on developing an updated force structure for the latest PPBES cycle mid-range period. This process is known as Total Army Analysis (TAA).

The principal aim of TAA is to develop the general purpose force and support force structures capable of sustaining tactical operations against the expected mid-range threat. The War Plans Division in the ODCSOPS must provide the primary force. In TAA-05, and as depicted above, the War Plans Division designated the primary force as the MTW force or the forces required to fight two simultaneous MTWs; forces required to train, equip, and deploy the MTW force; and any unique forces that are not elements of the other two. These forces were designated as modification table of organization and equipment (MTOE), table of distribution and allowances (TDA), or uncommitted.



Background - New Methodology

TAA-07 Force Accounting

Step 1: ID Current MTOF

Step 2: ID MTOF Still Needed

Step 3: ID Additional Requirements

Step 4: Build Additional MTOF

Step 5: Separate Additive vs Lesser Included

Step 6: Determine Baseline Force Required

Center for Army Analysis
MTOF 1
MTOF 2
MTOF 3
MTOF 4
MTOF 5
MTOF N
MTOF 1
MTOF 4
MTOF M
BGF
Strategic Reserve
Home Def
BEF
SSC
MTOF A
MTOF B
MTOF C
MTOF D
MTOF Z
MTOF MTW
MTOF MTW
MTOF D
MTOF O
MTOF Z
MTOF MTW
MTOF MTW
BGF
Strategic Reserve
Home Def
BEF
SSC

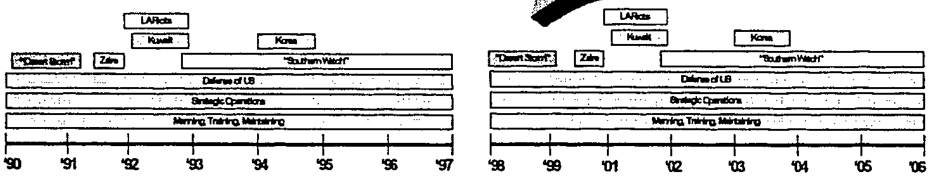
For TAA-07, the War Plans Division elected to employ elements of a new force planning process developed by the Center for Army Analysis (CAA) that established the concept and methodology for development of MTOFs as a primary force planning building block. This figure depicts the steps used to determine the baseline force for TAA-07.

Step 1 of this new methodology requires the identification of current MTOFs developed during the Quadrennial Defense Review (QDR) and which currently exist in the US Army. An MTOF is a force list together with an associated set of objectives and tasks to be accomplished under specified condition and standard for a specific mission. In step 2, MTOFs identified in step 1 are assessed to determine whether or not they are still required. Step 3 involves the identification of new requirements not addressed during the past TAAs. This includes the forces required for the Strategic Reserve, Homeland Defense, Base Engagement Force (BEF), and SSC operations. Once new requirements are identified, step 4 requires MTOFs to be constructed for each new mission. Step 5 entails consolidation of MTOFs in cases where (1) the MTOF can be satisfied by the MTW force (i.e., lesser included), or (2) the MTOF is required in addition to the MTW force (i.e., additive). In step 6, required MTOFs are listed following the consolidation process.

Given the new ODCSOPS approach to determining the baseline force for TAA-07, there is a need for a systematic process that will determine the number of simultaneously occurring SSCs in the mid-range future. A previous attempt by the Joint Staff to forecast simultaneous SSCs is discussed next.

Background - Previous Forecast

- J8 Dynamic Commitment IV.
  - Baseline Scenario.
    - Layout Analysis (event initiations per year, ongoing events per year, # of deployments during year).
    - Restrictions (nonpermissive NEOs, small crisis response, etc.).
  - Wargame Vignette.
  - Situation Template.


LA Riots
Kuwait
Korea
"Desert Storm"
Zaire
"Southern Watch"
Defense of US
Strategic Operations
Manning, Training, Maintaining
'90
'91
'92
'93
'94
'95
'96
'97
LA Riots
Kuwait
Korea
"Desert Storm"
Zaire
"Southern Watch"
Defense of US
Strategic Operations
Manning, Training, Maintaining
'98
'99
'01
'02
'03
'04
'05
'06

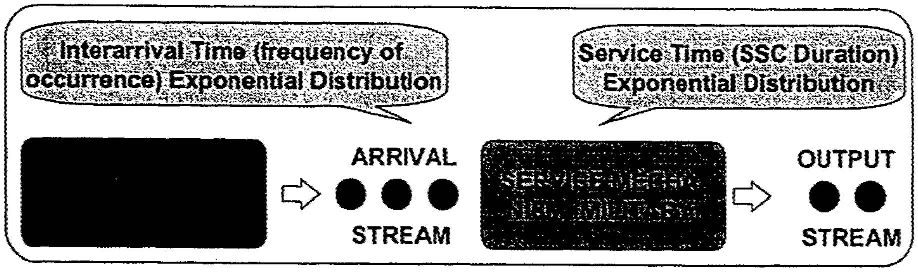
The US military has attempted to assess the uncertainty associated with MTWs and SSCs through a series of military games sponsored by the Joint Staff (J8) called Dynamic Commitment. Dynamic Commitment IV was the most recent exercise and was conducted from December 1996 to May 1997. The designers of the game developed a template of events using past events. The figure above depicts a partial template of events involving US military commitment between 1990 and 1997.

The Dynamic Commitment game requires each military service to provide the necessary resources at the appropriate time according to the prescribed scenario. The Game allows the military to determine whether the present force structure is able to satisfy the resource demands of the future.

Using the template of historical events, the game designers determined the event types (by percent of total), average event initiations, average number of events per year, average number of personnel/equipment committed per year, etc. Following the collection of these statistics, the game designers used these statistics, combined with intelligence-generated historical vignettes, to create a future scenario which looked nearly identical to the past scenario except for the dates and which is also illustrated above.

The process or model used in Dynamic Commitment IV is deterministic. A deterministic model ignores the uncertainty associated with real-world events; this limits the scope of the model, making it, at best, only capable of using past experiences as a direct predictor of future world problems. SADE/SARDE is a different methodology, one based upon queuing theory and incorporating stochastic processes and simulation. This new methodology makes it possible to "come to grips" with the uncertainty involved in forecasting the number of SSCs, by type, in which the US military could be involved during the period 1998 to 2006.

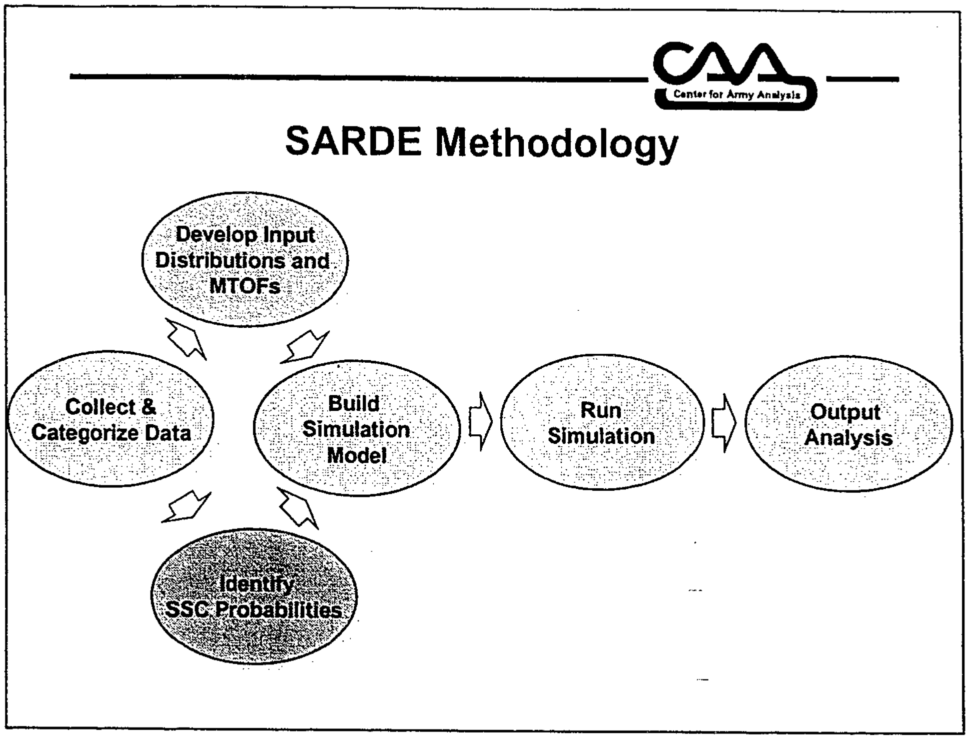
SARDE Methodology - Queuing Analogy


Interarrival Time (frequency of occurrence) Exponential Distribution
Service Time (SSC Duration) Exponential Distribution
ARRIVAL
STREAM
SERVICE MECHA-
NISM (MILITARY)
OUTPUT
STREAM

Given the complexity of forecasting the number of US Army units required to service simultaneous SSCs in which the US military could be involved during the period 1998 to 2006, numerous forecasting techniques are available to solve the problem. This report uses simulation modeling as its primary problem solving method.

In order to solve a problem using simulation modeling, it is necessary to understand and define the problem within the context of a system (Emshoff and Sisson, 1970). This system can be represented by a queuing or waiting line system. Queuing theory can help explain the average waiting time of a McDonald's customer or the average utilization of a McDonald's employee (Buffa, 1972). This study proposes that the theory used to analyze a McDonald's operating system can also be used to forecast the number of US Army units required to service SSCs in which the US military could be involved during the period 1998 to 2006.

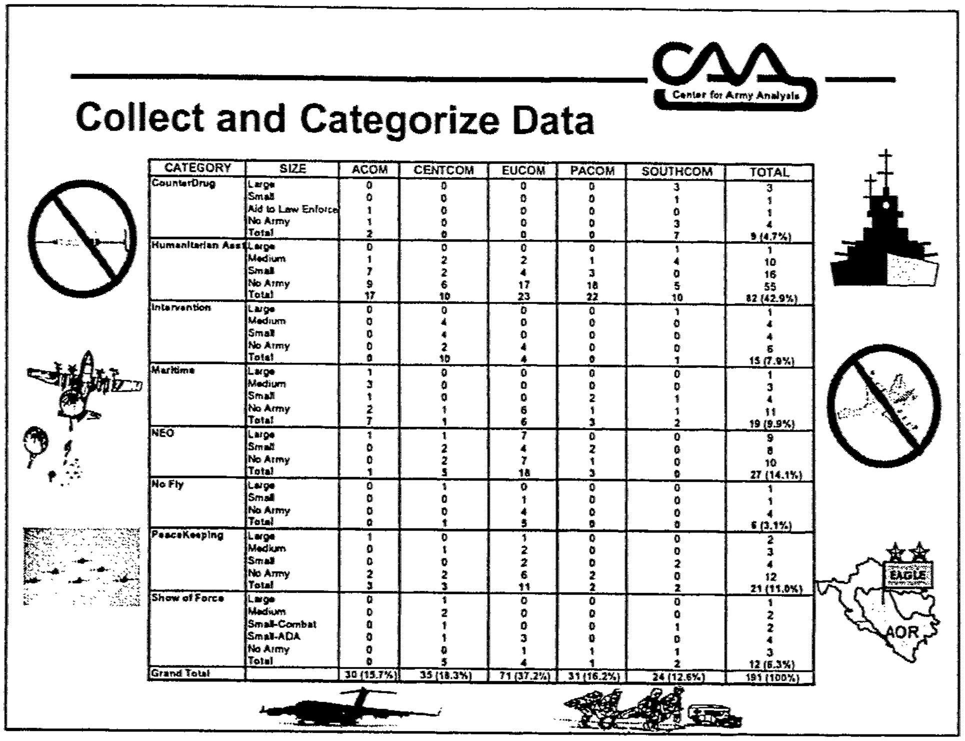
The figure above depicts the key items of a queuing system, namely the calling population and the service mechanism. In the SSC system, the calling population is the occurrence of the SSC, and the service mechanism is the US military's response. Every system requires interaction between the key items in order for it to be considered a system. Common interaction parameters for key items in a standard queuing system are the interarrival time of the calling population or time between successive SSC arrivals and the service time or SSC duration.



SARDE Methodology

Develop Input Distributions and MTOFs
Collect & Categorize Data
Build Simulation Model
Run Simulation
Output Analysis
Identify SSC Probabilities

The steps used to build the model, hereafter called the SARDE methodology, are depicted above. They include: 1) collect and categorize data; 2a) develop input distributions and MTOFs; 2b) identify SSCs and required force structure size probabilities; 3) build simulation model; 4) run simulation; and 5) conduct output analysis.

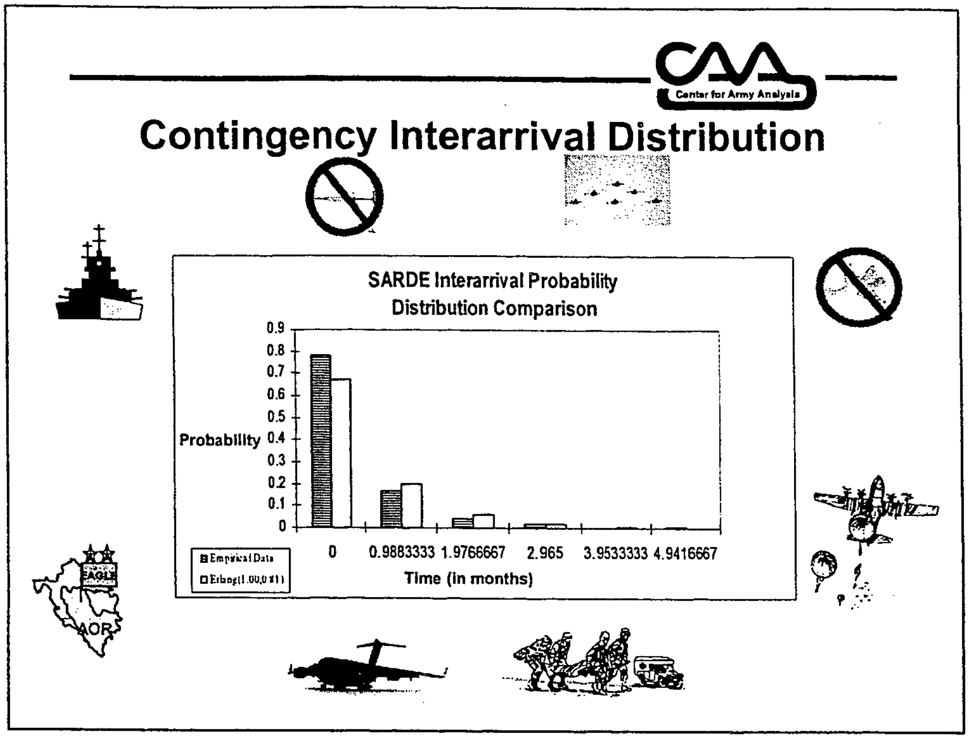


Collect and Categorize Data

CATEGORY	SIZE	ACOM	CENTCOM	EUCOM	PACOM	SOUTHCOM	TOTAL
CounterDrug	Large	0	0	0	0	3	3
	Small	0	0	0	0	1	1
	Aid to Law Enforce	1	0	0	0	0	1
	No Army	1	0	0	0	3	4
	Total	2	0	0	0	7	9 (4.7%)
Humanitarian Asst	Large	0	0	0	0	1	1
	Medium	1	2	2	1	4	10
	Small	7	2	4	3	0	16
	No Army	9	6	17	18	5	55
	Total	17	10	23	22	10	82 (42.9%)
Intervention	Large	0	0	0	0	1	1
	Medium	0	4	0	0	0	4
	Small	0	4	0	0	0	4
	No Army	0	2	4	0	0	6
	Total	0	10	4	0	1	15 (7.9%)
Maritime	Large	1	0	0	0	0	1
	Medium	3	0	0	0	0	3
	Small	1	0	0	2	1	4
	No Army	2	1	6	1	1	11
	Total	7	1	6	3	2	19 (9.9%)
NEO	Large	1	1	7	0	0	9
	Small	0	2	4	2	0	8
	No Army	0	2	7	1	0	10
	Total	1	5	18	3	0	27 (14.1%)
No Fly	Large	0	1	0	0	0	1
	Small	0	0	1	0	0	1
	No Army	0	0	4	0	0	4
	Total	0	1	5	0	0	6 (3.1%)
PeaceKeeping	Large	1	0	1	0	0	2
	Medium	0	1	2	0	0	3
	Small	0	0	2	0	2	4
	No Army	2	2	6	2	0	12
	Total	3	3	11	2	2	21 (11.0%)
Show of Force	Large	0	1	0	0	0	1
	Medium	0	2	0	0	0	2
	Small-Combat	0	1	0	0	1	2
	Small-ADA	0	1	3	0	0	4
	No Army	0	0	1	1	1	3
	Total	0	5	4	1	2	12 (6.3%)
Grand Total		30 (15.7%)	35 (18.3%)	71 (37.2%)	31 (16.2%)	24 (12.6%)	191 (100%)

Collect Data. Dynamic Commitment IV provides a starting point to identify past SSCs involving the US military. The Dynamic Commitment IV exercise identified 53 "named" operations involving the deployment, since 1990, of a substantial number of US forces under orders issued by the US National Command Authority (NCA). The RAND Corporation (Pirnie and Webb, 1996) identified additional US military-involved SSC operations, thus bringing the total to 110. Other sources that either verified identified SSCs or contributed new ones are a draft Secretary of Defense (SECDEF) report to Congress titled "US Military Involvement in Post Gulf War Major Contingency and Ongoing Operations," dated 12 March 1999; SSC data base developed by Dr. Mick Schubert, joint historian; and a secure Navy web site that tracks military operations for the Chief of Naval Operations (CNO). With these additional resources, the total number of identified SSCs that have occurred since January 1990 is 191.

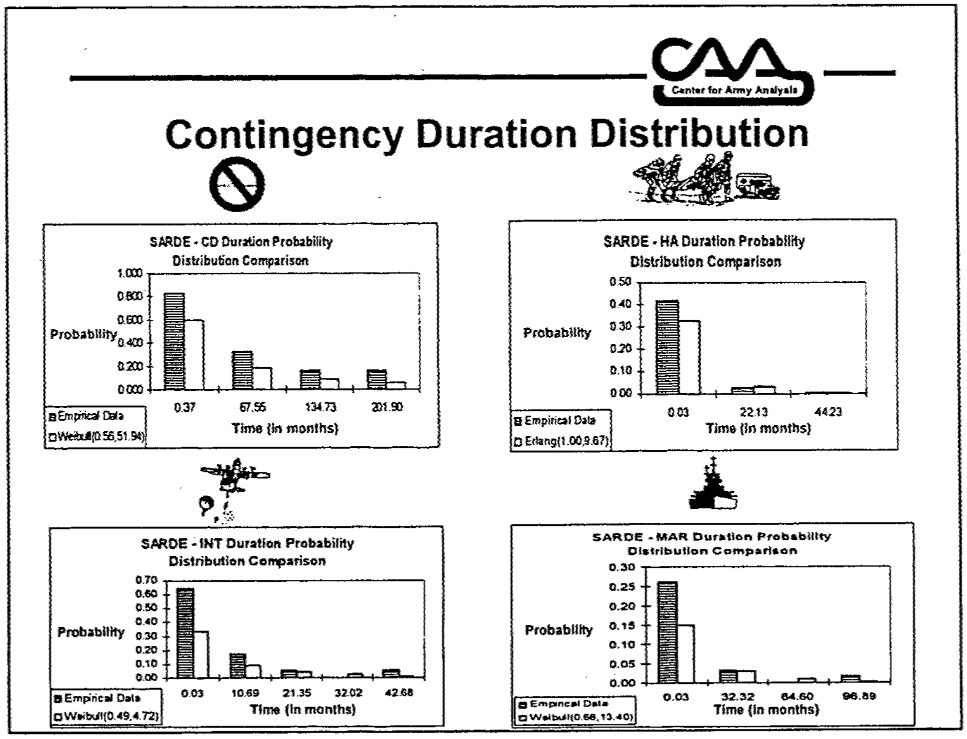
Categorize Data. In order to adequately categorize data, a balance must be achieved between having sufficient categories to address the key characteristics that identify each type of SSC and having an adequate number of data points per category to support the statistical analysis necessary for the simulation. The Defense Planning Guidance (DPG) has categorized the operations into the following 13 different types: opposed intervention, humanitarian intervention, strike, peace accord implementation, follow-on peace operations, interpositional peacekeeping, foreign humanitarian assistance, domestic disaster assistance, no fly, maritime intercept, support to domestic authority, noncombatant evacuation operation (NEO), and show of force. Definitions of each can be found in the DPG or US Army Field Manual (FM) 100-5. In an attempt to satisfy the balance between distinguishing between SSC types and having sufficient data points per category, some of the DPG categories were combined, resulting in these eight categories: intervention, peacekeeping, humanitarian assistance, no fly, maritime intercept, support to domestic authority or counterdrug, NEO, and show of force. To account for the magnitude of the US commitment, each SSC category was subdivided, in most cases, to small, medium, large, and no US Army commitment. The results of the categorization process are depicted above.



Contingency Interarrival Distribution

Introduction. As discussed previously, the input probability distributions required for the SARDE model are for the interarrival times for all SSCs and the duration times of each SSC type. The procedure to develop the interarrival distribution is slightly different than the procedure to develop each SSC duration probability distribution. The interarrival distribution requires one task to be accomplished while each SSC type's duration probability distribution requires two tasks. In this report, the development of the interarrival probability distribution and the development of one duration probability distribution will be presented. The remaining duration probability distributions were developed using the same procedure that is demonstrated here.

Demonstrate the Development of the Interarrival Probability Distribution. To determine the interarrival probability distribution, the software Best Fit® produced by the Palisade Corporation was used. Best Fit® determines which common probability distribution function most likely represents the empirical data, using a chi-square or Kolmogorov-Smirnov or Anderson-Darling test as the criteria for goodness of fit. The chi-square test is valid for large sample sizes; therefore, it will be used for sample sizes greater than or equal to 30 (Banks and Carson, 1984). The Kolmogorov-Smirnov test is particularly useful when sample sizes are small; therefore, it will be used for sample sizes less than 30 as the criteria for best fit (Banks and Carson, 1984). The steps used to determine the interarrival probability distribution are: 1) sort SSC data base by start time so that the time between SSC arrivals can be computed and displayed; 2) copy/paste or export time between arrivals into Best Fit®; 3) Best Fit® calculates the probability distribution that most closely represents the empirical data using the Levenberg-Marquardt Method, given the chi-square goodness of fit test criteria (Palisade Corp., February 1996). For this SSC, the results of Best Fit®'s calculations are an Erlang distribution with a mean parameter of 0.809959 and an integer (shape) parameter of 1. This distribution passes the chi-square goodness of fitness test with a test value of 7.64 at the 0.17 level of significance. The distribution overlapping the empirical data is depicted above.


Center for Army Analysis

Contingency Duration Distribution

Development of the Duration Distribution. Two tasks must be performed to determine the duration probability distribution. First, an estimate must be computed for the duration of all ongoing missions within the SSC category. Then, a probability distribution can be developed in much the same manner as the interarrival distribution.

Ongoing SSC Ending Estimates. When this study began, 22 SSCs were active or ongoing. In order for the remaining life to be accounted for in the model, an estimate of this quantity was required. The assumption is made that the duration of each SSC is a random value. In the formulation below, T represents the random variable that assigns a real number, SSC duration, to all possible duration outcomes. The following steps were used to determine the estimated duration of ongoing SSC missions.

(1) Determine the best fit duration probability distribution, f(t), using data points by category for completed SSCs using the same technique described on the previous page.

(2) For each ongoing or active data point in the category, determine the duration to date, t.

(3) For each active SSC of duration-to-date t, use the steps immediately below to determine the expected value of the total duration T, where $E(T|T > t)$.

(a) Determine the probability that the duration is greater than the current duration-to-date, t. That is, determine

$$P(T > t) = \int_t^\infty f(x)dx$$

(Freund, 1992).

(b) Determine the expected value of the duration time given that the SSC has already gone time t,

$$E(T|T > t) = \frac{\int_t^\infty xf(x)dx}{\int_t^\infty f(x)dx}$$

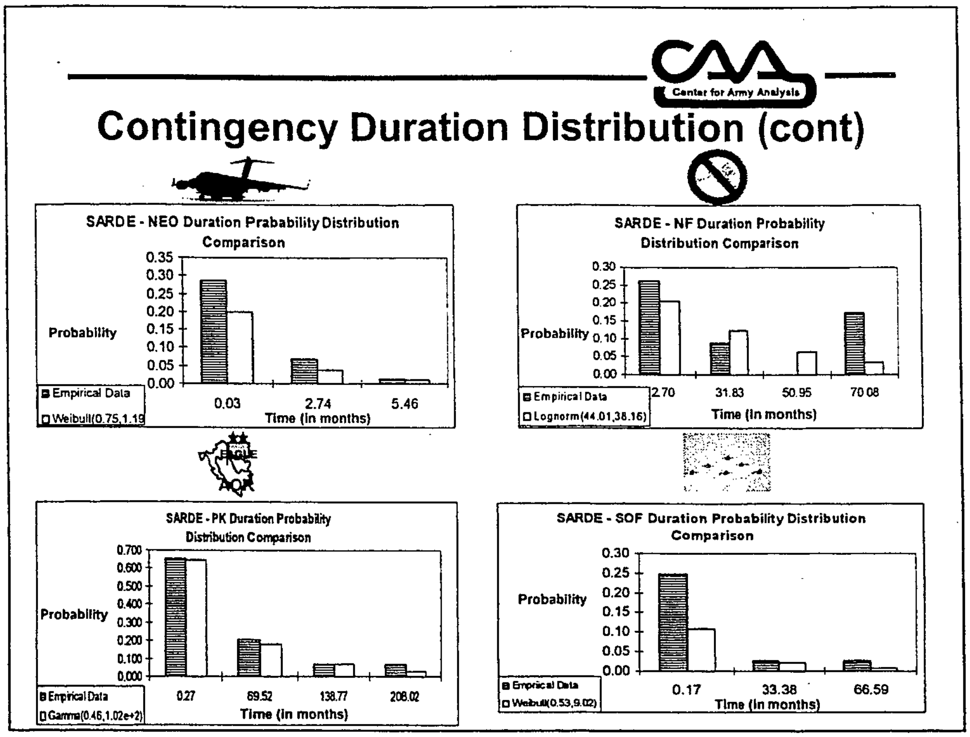
(Kalbfleisch and Prentice, 1980).

(4) Insert value found in step 3b back into the original data base for the applicable SSC category.

(5) Perform steps 3 and 4 for each data point associated with all ongoing SSCs within the category.

(6) Use step 1 on the revised data base category to determine the best fit.

The duration distributions overlapping the empirical data for counterdrug, humanitarian assistance, intervention, and maritime operations are depicted above.



Contingency Duration Distribution (cont)

SARDE - NEO Duration Prabability Distribution Comparison

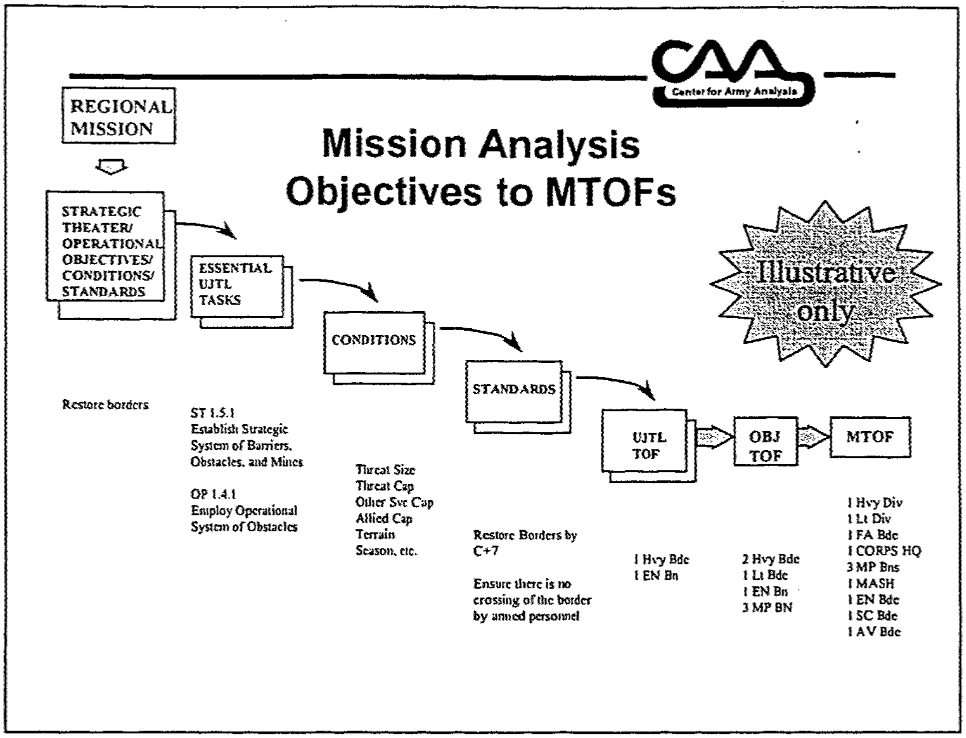
SARDE - NF Duration Probability Distribution Comparison

SARDE - PK Duration Probability Distribution Comparison

SARDE - SOF Duration Probability Distribution Comparison

The duration distributions overlapping the empirical data for NEO, no fly, peacekeeping, and show of force operations are depicted above.

A more detailed demonstration of this process can be found in a CAA Study Report, Stochastic Analysis for Deployments and Excursions, CAA-SR-98-6 (DuBois, 1999).



Mission Analysis
Objectives to MTOFs

Restore borders

ST 1.5.1
Establish Strategic System of Barriers, Obstacles, and Mines

OP 1.4.1
Employ Operational System of Obstacles

Threat Size
Threat Cap
Other Svc Cap
Allied Cap
Terrain
Season, etc.

Restore Borders by C+7

Ensure there is no crossing of the border by armed personnel

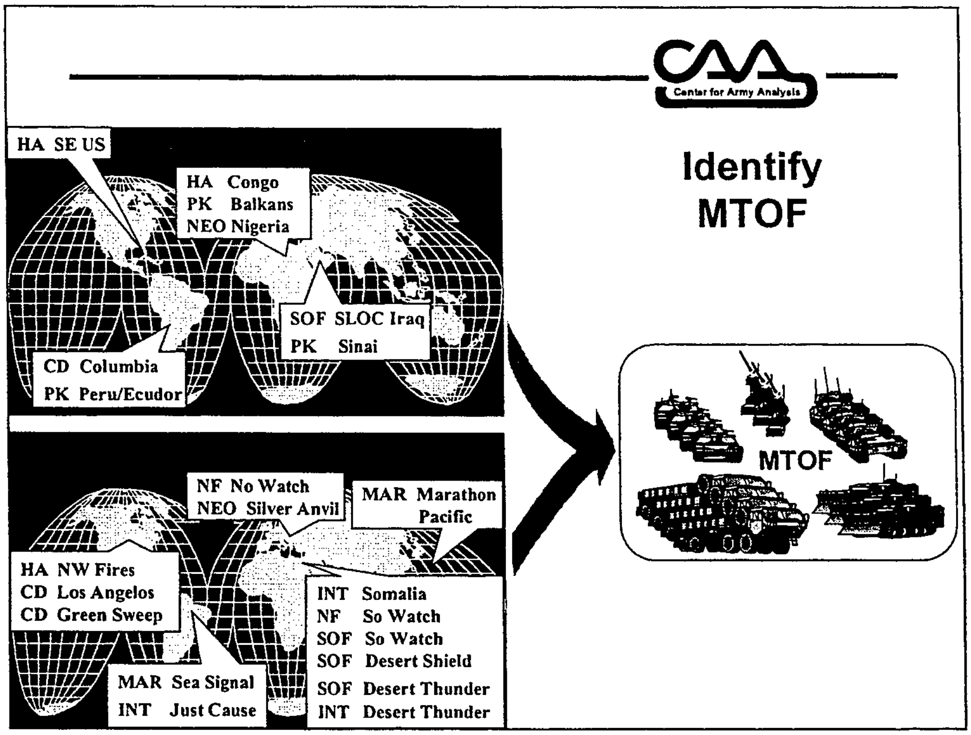
1 Hvy Bde
1 EN Bn

2 Hvy Bde
1 Lt Bde
1 EN Bn
3 MP BN

1 Hvy Div
1 Lt Div
1 FA Bde
1 CORPS HQ
3 MP Bns
1 MASH
1 EN Bde
1 SC Bde
1 AV Bde

General. Another SARDE model input variable is the forces that are applied to each SSC. Given the technique of using historical data to determine the other input variables, interarrival and duration probability distributions, a logical approach is to use historical force data. However, there are two reasons why this approach is not the first choice. First, in many cases, the deployed forces were not the appropriate forces. For example, upon entering Bosnia, the 1st Armor Division sent their artillery battalions back to Germany since there was no active role for them. Therefore, if the Bosnian deployed forces are used in the SARDE model, the peacekeeping requirements would be erroneous. To deal with this issue, CAA has developed a methodology called Objective Force Planning (OFP) which determines force requirements given a mission, conditions, and standards.

Objective Force Planning Methodology. The purpose of OFP is to determine the Army's mission-based force requirements in support of the National Military Strategy (NMS) (Arnwine, et. al.). OFP is not constrained to the scenarios that are specified in the DPG, but does include those scenarios and any missions the regional commanders in chief (CINCs) deem appropriate. These missions are a response to a threat or adversary based upon the threat intent and strategic objectives which are anticipated from a regional intelligence overview. Once the regional missions are identified, a linear, multistep process is followed as depicted above. In the ensuing steps, the appropriate US response is expressed in terms of CINCs' intent, strategic theater objectives, and strategic theater concept. Essential tasks, together with conditions and standards, are identified to support the identified objectives. Once essential tasks, conditions, and standards are identified, subject matter experts (SMEs) determine force capabilities or task organized forces (TOFs) that will accomplish the task given the conditions and standards. Once all TOFs are identified, a rollup or reconciliation process occurs to determine forces at the objective and mission level. The resultant mission force is called a mission task organized force (MTOF). These forces are requirements-based and are linked to the NMS.



Identify MTOF

Center for Army Analysis
HA SE US
HA Congo
PK Balkans
NEO Nigeria
SOF SLOC Iraq
PK Sinai
CD Columbia
PK Peru/Ecudor
NF No Watch
NEO Silver Anvil
MAR Marathon Pacific
HA NW Fires
CD Los Angelos
CD Green Sweep
INT Somalia
NF So Watch
SOF So Watch
SOF Desert Shield
SOF Desert Thunder
INT Desert Thunder
MAR Sea Signal
INT Just Cause
MTOF

Unfortunately, the OFP process is in its infant stage, causing MTOF shortages for some of the missions expected during the mid-range planning period. Therefore, where a requirements-based MTOF was not available to represent a mission type identified, an historical order of battle or force structure was used. The following table depicts the mission types, to include size and whether the forces used are based on an MTOF or historical order of battle.

Mission	Size	Name	MTOF	Historical Example
Counterdrug	Lrg	Columbia	X	
	Med	Green Sweep		X
	Law	JTF LA		X
Human. Asst.	Lrg	Congo	X	
	Med	SE U	X	
	Sm	NW Fires		X
Intervention	Lrg	Just Cause		X
	Med	Somalia		X
	Sm	Desert Thunder		X
Maritime	Lrg	Sea Signal		X
	Sm	Marathon Pacific		X
NEO	Lrg	Nigeria	X	
	Sm	Silver Anvil		X
No Fly	Lrg	Southern Watch		X
	Sm	Northern Watch		X
Peacekeeping	Lrg	Balkans	X	
	Med	Peru-Ecuador	X	
	Sm	Sinai	X	
Show of Force	Lrg	Desert Shield		X
	Med	SLOC Iraq	X	
	Sm-Cbt	Desert Thunder		X
	Sm-ADA	Southern Watch		X

SSC Type Probability Estimates

$P(\text{Counterdrug}) = 0.05$

$P(\text{Humanitarian Assistance Operation}) = 0.43$

$P(\text{Intervention}) = 0.08$

$P(\text{Maritime Operation}) = 0.10$

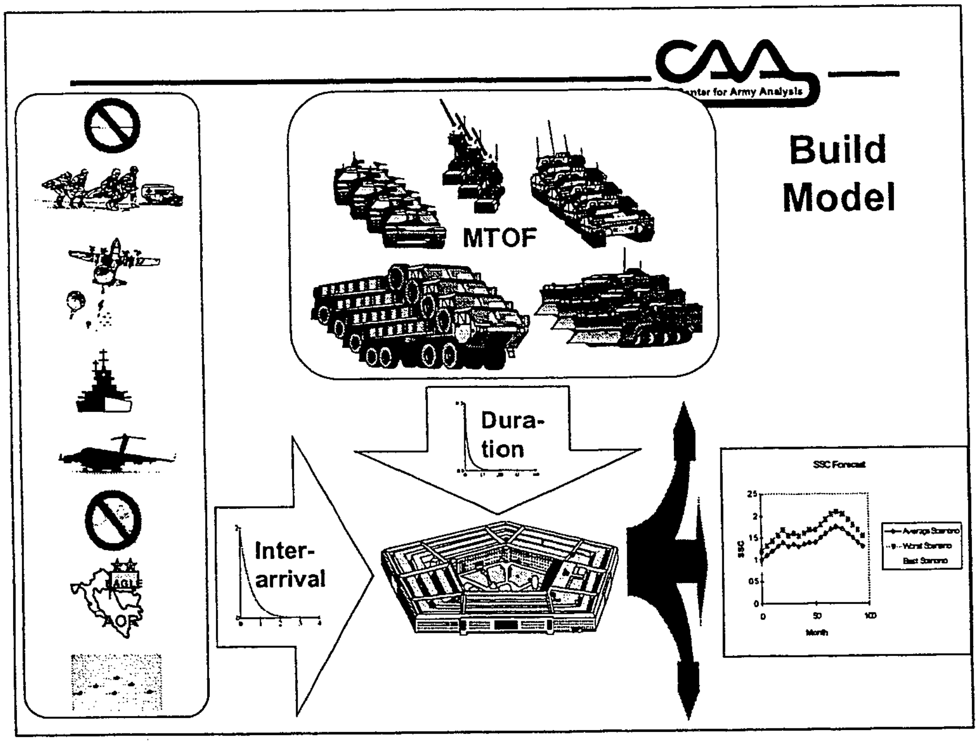
$P(\text{Noncombatant Evacuation Operation}) = 0.14$

$P(\text{No Fly Zone Enforcement}) = 0.03$

$P(\text{Peacekeeping Operation}) = 0.11$

$P(\text{Show of Force}) = 0.06$

The probability that an arriving SSC is of a particular type is simply based upon what percentage of the total number of SSCs is of that particular SSC type. Since there are 9 counterdrug SSCs in the historical data base of 191 SSCs, counterdrug SSCs comprise 5 percent of the total SSCs. The probabilities associated with the size (i.e., forces applied) of an SSC were determined by applying the same procedure.



Build Model

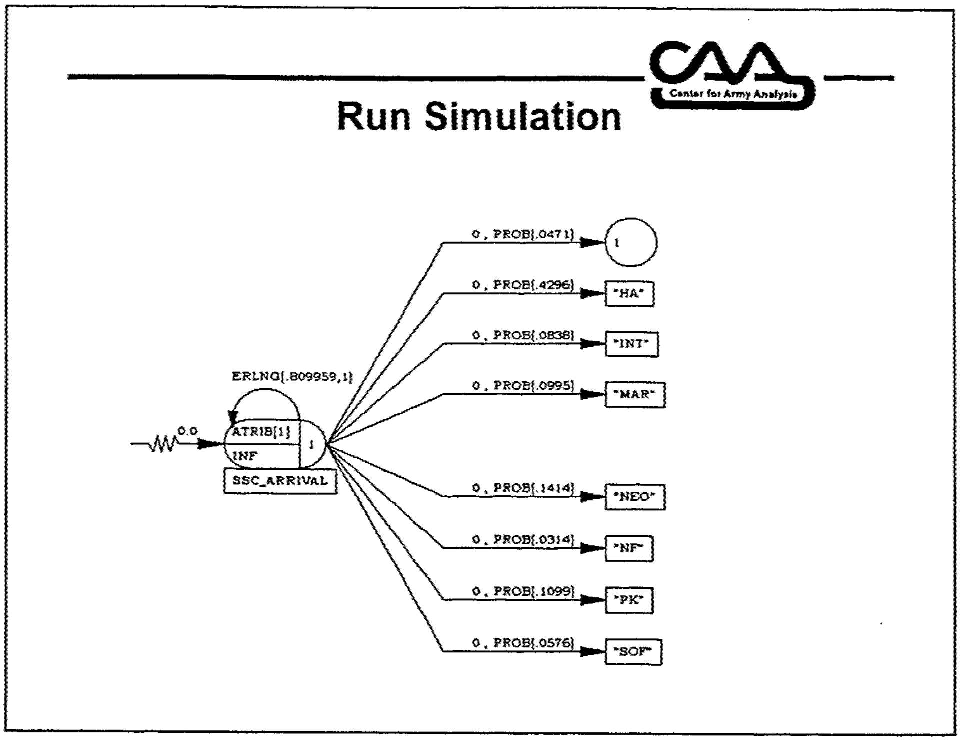
The slide above provides a graphical representation of the model.

General. By selecting a queuing model as the framework of this system, the elements and element interaction variables of the model are automatically defined. Next, select the simulation software and establish the initial conditions of the model.

Model Elements. As discussed above, the elements and interaction variables of the SSC system are automatically defined. The elements consist of the calling population/customer and the service mechanism/server or, in SARDE terminology, SSC and the US military's response, respectively. The interaction variables consist of the interarrival time probability distribution, the SSC type and size according to the probabilities identified by simple percentages, and the probability distribution of the duration of each SSC type.

Model Initial Conditions. Most simulation software permits the user to set initial conditions for the model. An example of an initial condition useable in the SARDE model is the existence of an SSC in the system at the beginning of model simulation.

Model Package. In order to model the SSC system, each combination of variable values representing a unique state or condition of the system must be manipulated to simulate movement of the system from state to state (Pritsker, O'Reilly, and LaVal, 1997). In order to perform this task, the analyst chose the simulation software called AweSim® manufactured by the Pritsker Corporation. AweSim® was selected due to the fact that it performs discrete simulation and is able to simulate a system by portraying the changes in the state of the system over time.



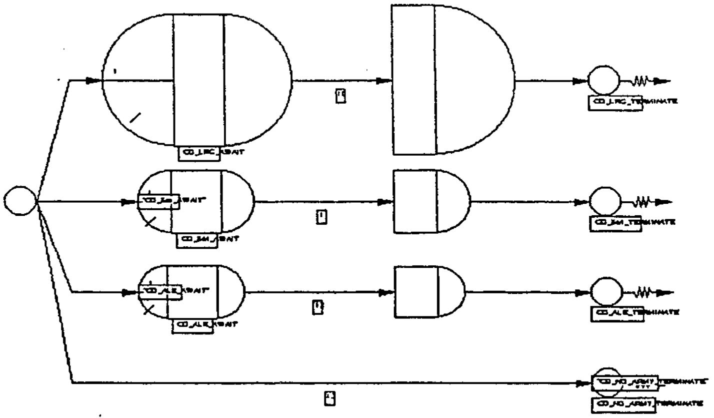
Center for Army Analysis

Run Simulation

ERLNG[.809959,1]
0.0
ATRIB[1]
INF
1
SSC_ARRIVAL
0 , PROB[.0471]
1
0 , PROB[.4296]
"HA"
0 , PROB[.0838]
"INT"
0 , PROB[.0995]
"MAR"
0 , PROB[.1414]
"NEO"
0 , PROB[.0314]
"NF"
0 , PROB[.1099]
"PK"
0 , PROB[.0576]
"SOF"

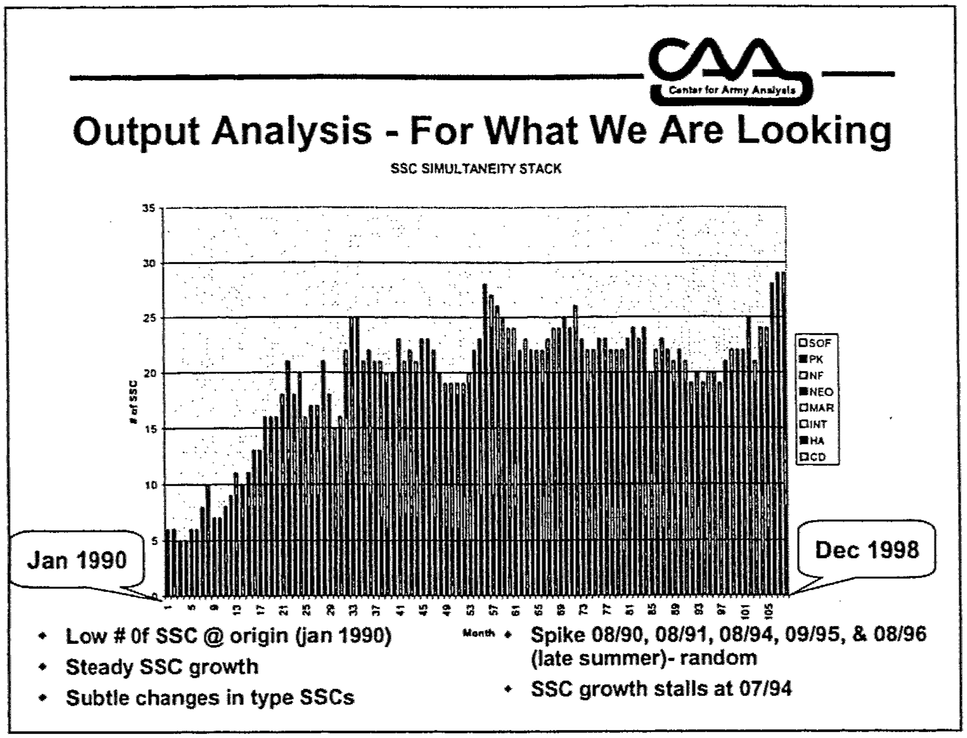
The figure above depicts the simulation model created with the AweSim® software package. The objects, as one looks at the diagram from left to right, are the CREATE node (SSCs created according the probability distribution Erlang (0.809959, 1)); eight ACTIVITIES that designate an SSC type according to a probability developed by the simple percentages method; and finally, labels that designate the network to which an entity will go once the entity reaches the label. The subsequent diagram depicts a follow-on network called "Counterdrug."

Run Simulation (cont)



The follow-on network called "Counterdrug" is the network to which entities go if they have been identified as a counterdrug SSC by the previous network. The objects, as one looks at the diagram from left to right, are as follows. GO ON node facilitates an entity to the next node. ACTIVITIES, which, according to a probability, designate the counterdrug SSC entity as a large, small, or aid to law enforcement counterdrug SSC. AWAIT node holds the counterdrug entity until the entity receives the resources or required forces. Another ACTIVITY designates the duration or how long the entity or counterdrug operation will last. FREE node releases the resources or forces after the counterdrug SSC is complete so that another SSC operation can use the resources or forces. ACTIVITY facilitates the counterdrug entity to the terminate node. Finally, the TERMINATE node ends the counterdrug entity because it is no longer required.

Prior to running this model, experimental controls are established so the simulation performs as desired. AweSim® has several statements that can be used to control the simulation. The most common include the GEN statement which specifies name, project, date, number of runs; LIMITS statement which specifies limits on the entities created in the model; and INITIALIZE statement which specifies the beginning and ending time of the simulation. The key values used in the control statements for this report are 100 runs, with each run ending after 206 periods (in this instance months) have been simulated. The number of 100 runs was selected to ensure a "good" representative sample of all combinations of input variables was obtained. The 206 periods was chosen so the simulation will not only simulate the period from which the data were taken (i.e., 1990 to 1997), but simulate 8.167 years into the future (i.e., 1998 to 2007).

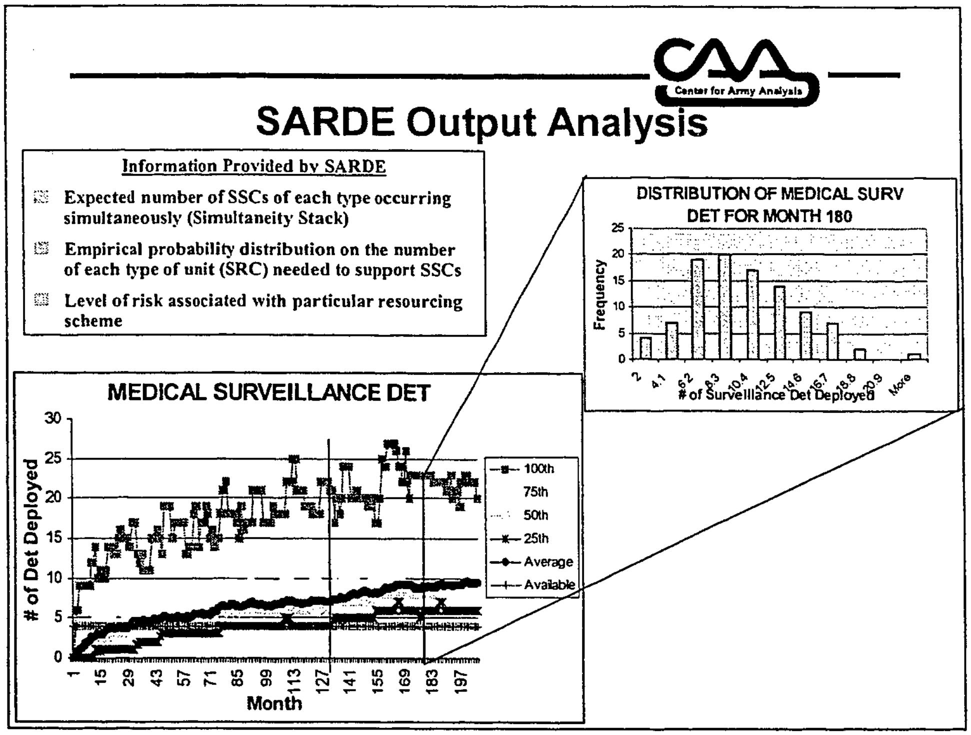


Output Analysis - For What We Are Looking

- Low # 0f SSC @ origin (jan 1990)
- Steady SSC growth
- Subtle changes in type SSCs
- Spike 08/90, 08/91, 08/94, 09/95, & 08/96 (late summer)- random
- SSC growth stalls at 07/94

As part of the run simulation step, model validation must be performed. Validation is the process of determining that a simulation run is performing as intended. A straightforward procedure to test for validation is to compare empirical data to simulation-produced data. If both sets of data appear similar, then validation is achieved. The figure above depicts the empircal simultaneity stacks, which indicate the number of SSCs, by type, that occurred from January 1990 to December 1998.

General characteristics of the empircal simultaneity stacks include a low number of SSCs at the origin; steady SSC growth for the first 34 months (i.e., January 1990 to October 1992); subtle changes in SSC types per period; peaks and valleys throughout the period of time as one would expect from a random process; and an SSC growth stall in July 1994. Furthermore, the simultaneity stack above can be compared to a simultaneity stack of a run from the simulation model. Although not shown, the simultaneity stack of one run from the simulation had very similar characteristics to the empirical simultaneity stack. Those characteristics include a low number of SSCs at the origin; steady SSC growth for the first 34 months (January 1990 to October 1992); subtle changes in the SSC types per period; peaks and valleys throughout the period as one would expect from a random process; and SSC growth stall in December 1996. All of these characteristics are very similar to the characteristics identified from the empirical simultaneity stacks. Given this similarity, one can conclude that the model is validated.



SARDE Output Analysis

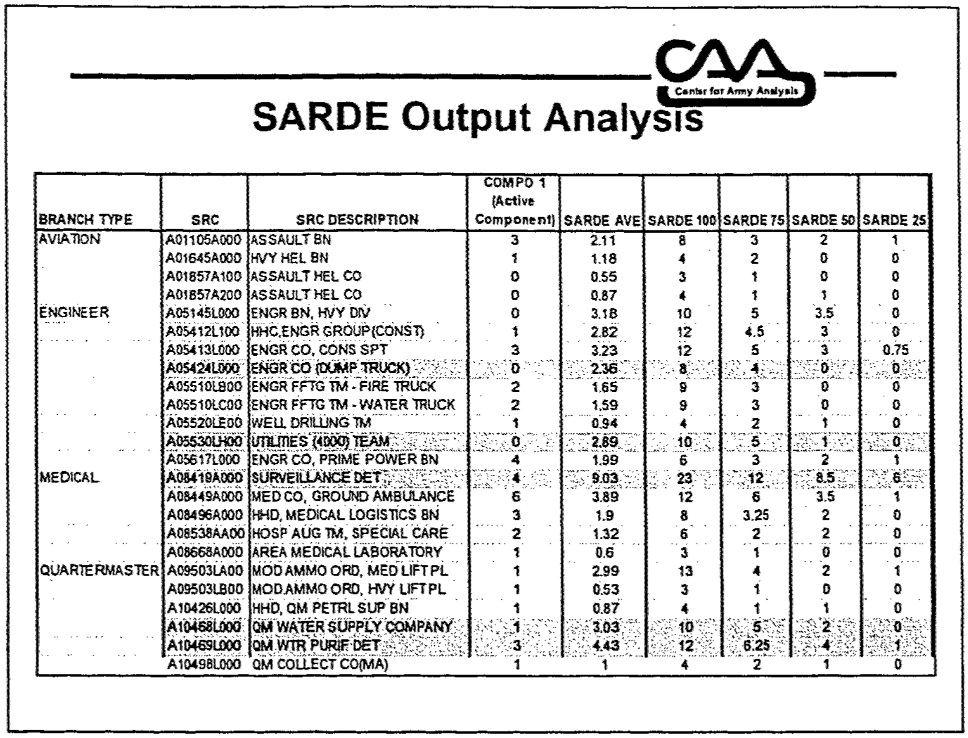
Information Provided by SARDE

- Expected number of SSCs of each type occurring simultaneously (Simultaneity Stack)
- Empirical probability distribution on the number of each type of unit (SRC) needed to support SSCs
- Level of risk associated with particular resourcing scheme

As stated previously, the benefit of simulation is its ability to depict the multiple combinations of variable values representing the unique states of the system. A technique used to depict the multiple states of a system is to present output percentiles. Percentiles are values on a scale of 100 indicating the percent of a distribution that is equal to or below it. The figure above depicts the 100th, 75th, 50th, and 25th percentiles of the simulation output distribution. The simulation output distribution, in this instance, is the estimated number of medical surveillance detachments in the Active Component of the US Army.

This figure depicts the number of medical surveillance detachments per month (the 192 months associated with the period January 1990 to December 2005) for the 100th, 75th, 50th, and 25th percentile of the simulation output distribution. For example, the bar representing month 132, which corresponds to January 2001, has values of 5, 7, 9, and 21 for the 25th, 50th, 75th, and 100th percentiles, respectively. Since there were 100 simulation runs, the 50th percentile indicates that 50 runs estimated 7 or less medical surveillance detachments and 50 runs estimated greater than 7 medical surveillance detachments. Taking the percentile concept a step further, the interpretation could be made that by designing the Army force using the 50th percentile, the Army would assume 50 percent risk. That is, 50 percent of the time, a force designed using the 50th percentile will be inadequate to satisfy requirements. The line associated with the 100th percentile can also be described as the 0 percent risk line, just as the 75th percentile line can also be described as the 25 percent risk line. Hence, risk terminology can be used to account for the percent of missions that the designed force will not satisfy mission requirements.

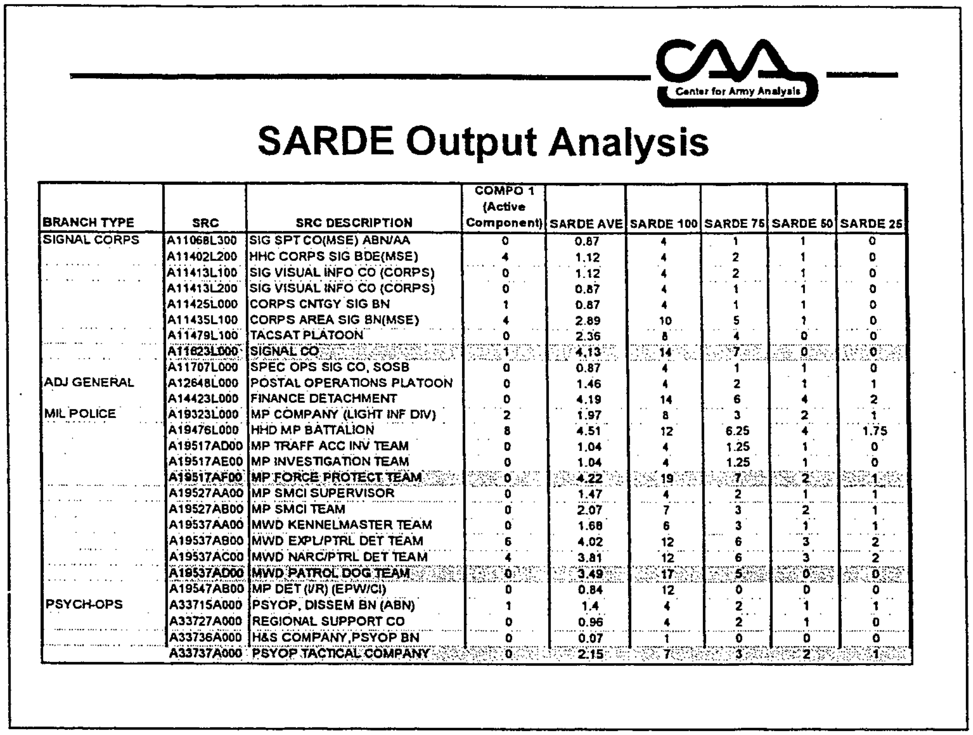
Another line of note in the figure above is the "Available" line. This line indicates the number of medical surveillance detachments currently in the Active Component, COMPO 1, of the US Army. Given the future medical surveillance detachments estimates of 5, 7, 9, and 21 according to 75, 50, 25, and 0 percent risk, the US Army is assuming a great deal of risk--approximately 75 percent.



SARDE Output Analysis

BRANCH TYPE	SRC	SRC DESCRIPTION	COMPO 1 (Active Component)	SARDE AVE	SARDE 100	SARDE 75	SARDE 50	SARDE 25
AVIATION	A01105A000	ASSAULT BN	3	2.11	8	3	2	1
	A01645A000	HVY HEL BN	1	1.18	4	2	0	0
	A01857A100	ASSAULT HEL CO	0	0.55	3	1	0	0
	A01857A200	ASSAULT HEL CO	0	0.87	4	1	1	0
ENGINEER	A05145L000	ENGR BN, HVY DIV	0	3.18	10	5	3.5	0
	A05412L100	HHC,ENGR GROUP(CONST)	1	2.82	12	4.5	3	0
	A05413L000	ENGR CO, CONS SPT	3	3.23	12	5	3	0.75
	A05424L000	ENGR CO (DUMP TRUCK)	0	2.36	8	4	0	0
	A05510LB00	ENGR FFTG TM - FIRE TRUCK	2	1.65	9	3	0	0
	A05510LC00	ENGR FFTG TM - WATER TRUCK	2	1.59	9	3	0	0
	A05520LE00	WELL DRILLING TM	1	0.94	4	2	1	0
	A05530LH00	UTILITIES (4000) TEAM	0	2.89	10	5	1	0
	A05617L000	ENGR CO, PRIME POWER BN	4	1.99	6	3	2	1
MEDICAL	A08419A000	SURVEILLANCE DET	4	9.03	23	12	8.5	6
	A08449A000	MED CO, GROUND AMBULANCE	6	3.89	12	6	3.5	1
	A08496A000	HHD, MEDICAL LOGISTICS BN	3	1.9	8	3.25	2	0
	A08538AA00	HOSP AUG TM, SPECIAL CARE	2	1.32	6	2	2	0
	A08668A000	AREA MEDICAL LABORATORY	1	0.6	3	1	0	0
QUARTERMASTER	A09503LA00	MOD AMMO ORD, MED LIFT PL	1	2.99	13	4	2	1
	A09503LB00	MOD AMMO ORD, HVY LIFT PL	1	0.53	3	1	0	0
	A10426L000	HHD, QM PETRL SUP BN	1	0.87	4	1	1	0
	A10468L000	QM WATER SUPPLY COMPANY	1	3.03	10	5	2	0
	A10469L000	QM WTR PURIF DET	3	4.43	12	6.25	4	1
	A10498L000	QM COLLECT CO(MA)	1	1	4	2	1	0

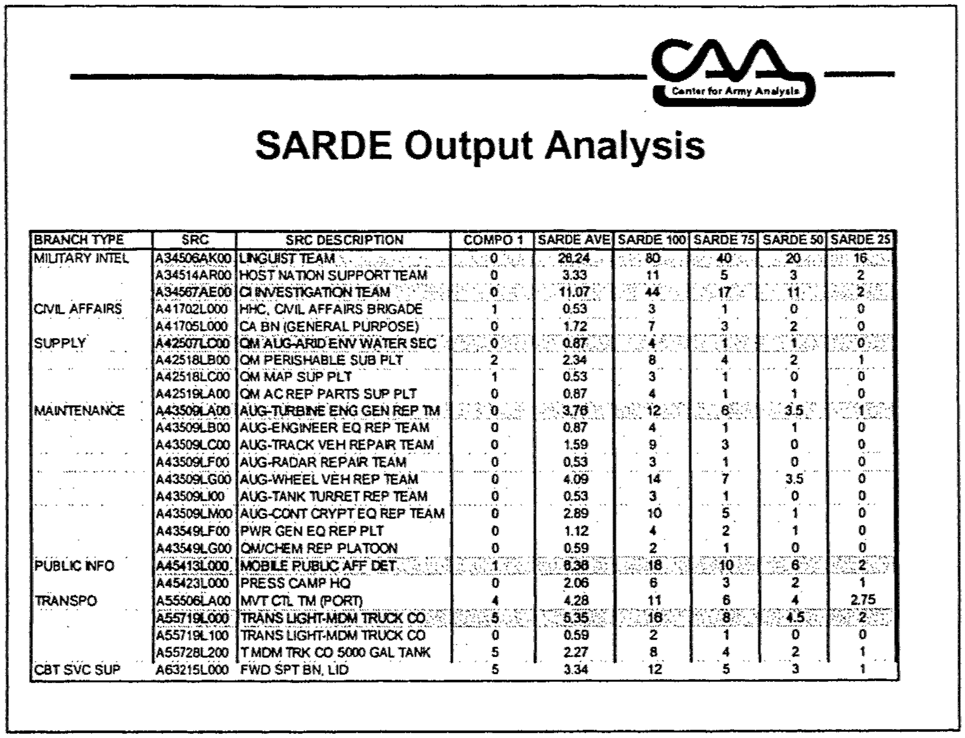
This table shows unit types for four US Army branches. In addition to each unit type, the unit's number in the Active Component is provided, as well as the SARDE estimate at the 100th, 75th, 50th, and 25th percentiles. The unit types highlighted indicate that SARDE estimates, showing the unit's future utilization, are much higher than what the Active Component of the US Army currently has available. These units include engineer dump truck companies, utilities teams, medical surveillance detachments, quartermaster water supply companies, and quartermaster water purification companies.



SARDE Output Analysis

BRANCH TYPE	SRC	SRC DESCRIPTION	COMPO 1 (Active Component)	SARDE AVE	SARDE 100	SARDE 75	SARDE 50	SARDE 25
SIGNAL CORPS	A11068L300	SIG SPT CO(MSE) ABN/AA	0	0.87	4	1	1	0
	A11402L200	HHC CORPS SIG BDE(MSE)	4	1.12	4	2	1	0
	A11413L100	SIG VISUAL INFO CO (CORPS)	0	1.12	4	2	1	0
	A11413L200	SIG VISUAL INFO CO (CORPS)	0	0.87	4	1	1	0
	A11425L000	CORPS CNTGY SIG BN	1	0.87	4	1	1	0
	A11435L100	CORPS AREA SIG BN(MSE)	4	2.89	10	5	1	0
	A11479L100	TACSAT PLATOON	0	2.36	8	4	0	0
	A11623L000	SIGNAL CO	1	4.13	14	7	0	0
	A11707L000	SPEC OPS SIG CO, SOSB	0	0.87	4	1	1	0
ADJ GENERAL	A12648L000	POSTAL OPERATIONS PLATOON	0	1.46	4	2	1	1
	A14423L000	FINANCE DETACHMENT	0	4.19	14	6	4	2
MIL POLICE	A19323L000	MP COMPANY (LIGHT INF DIV)	2	1.97	8	3	2	1
	A19476L000	HHD MP BATTALION	8	4.51	12	6.25	4	1.75
	A19517AD00	MP TRAFF ACC INV TEAM	0	1.04	4	1.25	1	0
	A19517AE00	MP INVESTIGATION TEAM	0	1.04	4	1.25	1	0
	A19517AF00	MP FORCE PROTECT TEAM	0	4.22	19	7	2	1
	A19527AA00	MP SMCI SUPERVISOR	0	1.47	4	2	1	1
	A19527AB00	MP SMCI TEAM	0	2.07	7	3	2	1
	A19537AA00	MWD KENNELMASTER TEAM	0	1.68	6	3	1	1
	A19537AB00	MWD EXPL/PTRL DET TEAM	6	4.02	12	6	3	2
	A19537AC00	MWD NARC/PTRL DET TEAM	4	3.81	12	6	3	2
	A19537AD00	MWD PATROL DOG TEAM	0	3.49	17	5	0	0
	A19547AB00	MP DET (I/R) (EPW/CI)	0	0.84	12	0	0	0
PSYCH-OPS	A33715A000	PSYOP, DISSEM BN (ABN)	1	1.4	4	2	1	1
	A33727A000	REGIONAL SUPPORT CO	0	0.96	4	2	1	0
	A33736A000	H&S COMPANY,PSYOP BN	0	0.07	1	0	0	0
	A33737A000	PSYOP TACTICAL COMPANY	0	2.15	7	3	2	1

This table shows unit types for four US Army branches. In addition to each unit type, the unit's number in the Active Component is given, as well as the SARDE estimate at the 100th, 75th, 50th, and 25th percentiles. The unit types highlighted indicate that SARDE estimates, showing the unit's future utilization, are much higher than what the Active Component of the US Army currently has available. These units include signal companies, military police fire protection teams, patrol dog teams, and psychological operations tactical teams.

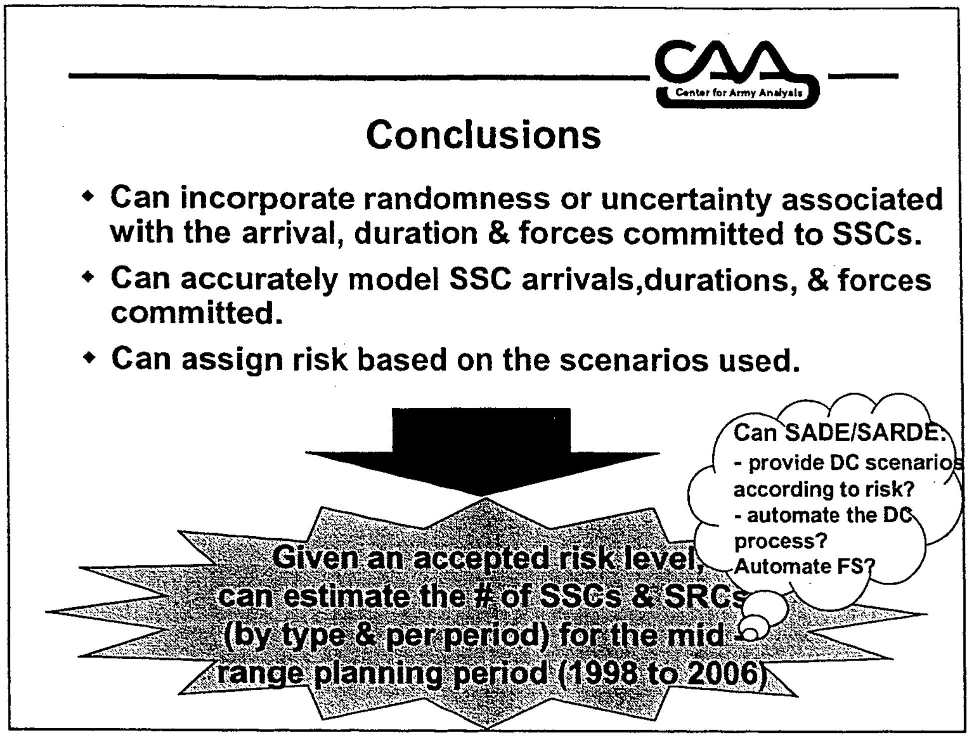


Center for Army Analysis

SARDE Output Analysis

BRANCH TYPE	SRC	SRC DESCRIPTION	COMPO 1	SARDE AVE	SARDE 100	SARDE 75	SARDE 50	SARDE 25
MILITARY INTEL	A34506AK00	LINGUIST TEAM	0	28.24	80	40	20	16
	A34514AR00	HOST NATION SUPPORT TEAM	0	3.33	11	5	3	2
	A34567AE00	CI INVESTIGATION TEAM	0	11.07	44	17	11	2
CIVIL AFFAIRS	A41702L000	HHC, CIVIL AFFAIRS BRIGADE	1	0.53	3	1	0	0
	A41705L000	CA BN (GENERAL PURPOSE)	0	1.72	7	3	2	0
SUPPLY	A42507LC00	QM AUG-ARID ENV WATER SEC	0	0.87	4	1	1	0
	A42518LB00	QM PERISHABLE SUB PLT	2	2.34	8	4	2	1
	A42518LC00	QM MAP SUP PLT	1	0.53	3	1	0	0
	A42519LA00	QM AC REP PARTS SUP PLT	0	0.87	4	1	1	0
MAINTENANCE	A43509LA00	AUG-TURBINE ENG GEN REP TM	0	3.76	12	6	3.5	1
	A43509LB00	AUG-ENGINEER EQ REP TEAM	0	0.87	4	1	1	0
	A43509LC00	AUG-TRACK VEH REPAIR TEAM	0	1.59	9	3	0	0
	A43509LF00	AUG-RADAR REPAIR TEAM	0	0.53	3	1	0	0
	A43509LG00	AUG-WHEEL VEH REP TEAM	0	4.09	14	7	3.5	0
	A43509LI00	AUG-TANK TURRET REP TEAM	0	0.53	3	1	0	0
	A43509LM00	AUG-CONT CRYPT EQ REP TEAM	0	2.89	10	5	1	0
	A43549LF00	PWR GEN EQ REP PLT	0	1.12	4	2	1	0
	A43549LG00	QM/CHEM REP PLATOON	0	0.59	2	1	0	0
PUBLIC INFO	A45413L000	MOBILE PUBLIC AFF DET	1	8.38	18	10	6	2
	A45423L000	PRESS CAMP HQ	0	2.06	6	3	2	1
TRANSPO	A55506LA00	MVT CTL TM (PORT)	4	4.28	11	6	4	2.75
	A55719L000	TRANS LIGHT-MDM TRUCK CO	5	5.35	16	8	4.5	2
	A55719L100	TRANS LIGHT-MDM TRUCK CO	0	0.59	2	1	0	0
	A55728L200	T MDM TRK CO 5000 GAL TANK	5	2.27	8	4	2	1
CBT SVC SUP	A63215L000	FWD SPT BN, LID	5	3.34	12	5	3	1

This table shows unit types for seven US Army branches. In addition to each unit type, the unit's number in the Active Component is given, as well as the SARDE estimate at the 100th, 75th, 50th, and 25th percentiles. The unit types highlighted indicate that SARDE estimates, showing the unit's future utilization, are much higher than what the Active Component of the US Army currently has available. Those units include linguist teams, CI investigation teams, quartermaster environmental water section, turbine engine general repair team, mobile public affairs detachment, and a light-medium truck company.



Center for Army Analysis

Conclusions

- Can incorporate randomness or uncertainty associated with the arrival, duration & forces committed to SSCs.
- Can accurately model SSC arrivals,durations, & forces committed.
- Can assign risk based on the scenarios used.

Can SADE/SARDE:
- provide DC scenarios according to risk?
- automate the DC process?
Automate FS?

Given an accepted risk level, can estimate the # of SSCs & SRCs (by type & per period) for the mid-range planning period (1998 to 2006)

A stochastic methodology was developed and demonstrated that incorporates uncertainty inherent to SSCs to forecast the number of each standard requirement code (SRC) the US military might utilize during the period 1998 to 2006. The SARDE methodology is a five-step approach that incorporates stochastic processes which result in probability distributions for the number of each SRC required by type and per month from 1998 to 2006. The main contribution of the stochastic approach using simulation modeling is the quantification of the variability or uncertainty associated with the input parameters interarrival rate, SSC duration, and the magnitude of the support given to each SSC. By applying this methodology, the output distributions represent many combinations of the input parameters. Hence, a very complex problem can be summarized in an easy-to-read probability chart indicating the likelihood of different numbers of simultaneous SSCs.

For each SRC forecast, the SARDE methodology can assign risk levels. To incorporate this uncertainty of the queuing problem, 100 runs of the SARDE model were made. By performing these runs, the effects of many combinations of variable interarrival times of the calling population, the service duration of the service mechanism, and the magnitude of the commitment are taken into account. The combined effects of these variable input parameters form a range of SRC utilization during the forecasted period. The range of SRC utilization can be partitioned into percentile bands. In SARDE, the percentiles represent risk levels. For example, if the Army structure provided enough of a particular type of SRC to resource at the 75th percentile, the Army would assume a 25 percent risk. That is, 25 percent of the 100 runs would indicate more of a particular type of SRC is required than there is in the resourced Army structure. Therefore, senior Army leadership is able to determine the amount of risk that will be assumed based upon the force levels desired. In addition, and more importantly, the senior Army leadership can accurately convey to the NCA, Congress, Office of the Secretary of Defense, Joint Staff, and senior-level decision makers the amount of additional risk the Army will assume by further reducing force structure.

The units identified in SARDE as being dangerously low are the typical units often stated as being high OPTEMPO/PERSTEMPO. They include engineer, medical, quartermaster, signal, military police, transportation, and civil affairs. These units are used more as compared to combat units in SSCs than during MTWs.

APPENDIX A

REQUEST FOR ANALYTICAL SUPPORT

PART 1

REQUEST FOR ANALYTICAL SUPPORT

1. Performing Directorate/ Division: FS	**2. Account Number:** 99C12
3. Type Effort (Enter one): Q S - Study Q - QRA P - Project R - RAA M - MMS Mode (Contract=C) ☐	**4. Tasking (Enter one):** F F - Formal Directive I - Informal V - Verbal

5. Title: Stochastic Anal. of Resources for Deployments and Excursions

6. Acronym: SARDE	**7. Date Request Received:** 10/01/98	**8. Date Due:** 07/01/99

9. Requester/Sponsor (i.e., DCSOPS): DCSOPS	**10. Sponsor Division (i.e., SSW, N/A)** SSW

11. Impact on Other Studies, QRA, Projects, RAA: SADE

12. Product Required:

13. Estimated Resources Required:	a. Estimated PSM: 3.0	b. Estimated Funds:
c. Models Req'd: Yes		d. Other:

14. Objective(s)/Abstract:

The Center for Army Analysis will develop and demonstrate a stochastic methodology that forecasts the number of each type of Standard Requirement Code (SRC) by risk level that US military will require to service small-scale contingency (SSC) operations during the mid-range planning period, 1998-2006.

15. Study Director/POC:	Last Name: DuBois	First: Patrick	Date: 10/22/98
	Signature:		Phone#: 295-6931

GO TO BLOCK 20 *If this is A STUDY*. See Tab C of the Study Directors' Guide for preparation of a Formal Study Directive.

PART 2

16. Background/Statement of Problem*: Given US budgetary constraints, DOD and specifically the US Army are under increasing pressure to reduce force structure. Therefore, it is necessary to accurately forecast US Military force requirements so the force structure can be defended during budget cutting initiatives.

17. Scope of Work*: The source data is limited to the post cold war period (1990) to the present. The forecast period is from 1998 to 2006. The type of missions to analyze include all joint contingency missions conducted during the Post Cold War period by the US Military.

18. Issues for Analysis*:

19. Milestones/Plan of Action*:

Collect Data	31 Dec 98
Prototype Model	31 Mar 99
Provide Final Model	31 May 99
Provide Final Briefing/Report	30 Jun 99

20. Division Chief Concurrence:	COL Andrew G. Loerch	Date: 2/3/99
21. Sponsor (COL/DA Div Chief) Concurrence:	COL Hackerson	Date: 2/3/99

22. Sponsor Comments*:

CAA Form 233 (1 May 95) * Continue on separate sheet Previous editions Obsolete